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Analysis on renewable energy systems

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ABSTRACT

The most alarming feature today is how to manage the energy demand and crucial climate change. To run life among these major threats, a good idea is to penetrate renewable energy sources gradually into the global energy market. These renewables are the best alternative to conventional fuels because of their abundant potential, non-pollutant nature and are exceedingly eco-friendly with the environment. The major renewables include wind, solar and diesel energy sources with a safety battery back-up to challenge the energy disaster to a possible extent. In addition, minor sources like fuel cells, biomass and tidal energy can also be included if the load demand is high. The careful blending of these available resources and technologies facilitate economic and environmental benefits. This paper overviews the performance analysis of hybrid power systems, control methodologies and modeling techniques so as to get an optimum output power.

Contents

1. Introduction

Hybrid wind–solar–diesel systems are the recent trends in the field of power generation to wipe up the energy gloom and additional bonus in this energy catastrophe to meet the load demand without the risk of price hike in diesel in islands particularly where the utility gird is unavailable. Without the grid, the renewable generation is not easy in case of cage wound induction generator, which is very popular in wind mill sector. Renewable energy generation can be done in cage wound induction generator only when reactive power is supplied back from the utility grid. To overcome this grid issues and to have a green future, it is very much essential to develop a hybrid wind–solar–diesel system which will be more viable in terms of cost, efficiency etc.

However, the wind–solar–diesel parallel work has some drawbacks due to the stochastic nature of wind and unpredictable insolation of sun energy. Also since hybrid power system is much sensitive to load variations and fault conditions a dump load is necessary to protect against an excess power in the network. Many

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wind farms installed either off-shore or onshore would operate in variable speed and use doubly fed induction generators for the sake of network compatibility and easy handling of mechanical loads. In the imminent future the sun energy also takes equal part in meeting the load demand by its inexhaustible nature and ample potential, though the initial cost of installation is very high.

Reviewing the related literature on hybrid power systems explains various technological aspects such as design, analysis, modeling, simulation, control features and the fault management procedures. An effort has been taken to highlight these issues and a brief review of the recent publications has been carried out here. This paper is prepared in such a way that the Section 2 deals with the design concepts to be conceded while manufacturing the wind turbine, solar panels and diesel generator. The behavior of the whole system is analyzed by studying the static and dynamic characteristics of individual components. Section 3 describes the new approaches in control strategies and advanced modeling techniques used in wind electric generators. The common expected problems while modeling has been dealt with remedial measure in Section 4. Section 5 quotes the various testing methodologies and algorithms looking for optimum power both in wind and solar energy sources. The losses in converter side and thermal losses expected to occur in solar plate collectors are listed here in Section 6.

Section 7 ends with the conclusive comment that wind energy potential would meet five times the world energy demand with the aid of sun energy in the upcoming years.

2. System design

Hybrid power systems generally include wind turbines, solar panels, AC–DC–AC converter, diesel generator, battery unit and load. The non-deterministic wind blow, changing solar irradiance and cost of diesel all are compensated by a good hybrid system which is the best option now days but with hard-hitting tasks. The maximum possible speed range of wind, irradiance of solar and availability of diesel source by which optimum retrieval of power could be obtained are to be well analyzed using physical modeling of all the components. The dynamic modeling can be validated with its real time value in terms of speed of wind, power curve, overall efficiency, amplitude of DC link voltage and the controller characteristics. In order to mitigate the light load efficiency the generator volts per rpm can be increased which affects the ratings of the semiconductor in turn making the whole system expensive. An alternate solution may be the multilevel conversion with reconfigurable converters with suitable controller. The switching periods of the converter can be split in regular intervals and monitored by a controller through variety of algorithms.

Recent techniques like fuzzy control, neural networks and artificial intelligence can be tried to get an appropriate output without affecting the efficiency. On the whole, compromising the total cost, utmost hybrid system with remarkable efficiency and dwindling converter issues is to be developed. From the recent statistics it is found that the cumulative achievements in power generation include the retrieval of energy from wind power as 222 MW and 429 MW from solar power. The huge and most economic green energy project is successful by designing a complete hybrid power system with respect to their static and dynamic characteristics of the system, as it is highly nonlinear [1,2] and the performance can be analyzed considering the design of turbine blade size, nominal power output, shaft stiffness, losses, hub height, nacelle weight and gear box ratio to improve the rotational speed of wind turbine. The dynamic characteristics such as wind velocity, density of wind and the predominant wind direction have all to be monitored frequently such that pitch and yaw control mechanisms could be done inside nacelle of wind turbine itself which houses the generator, blades and gear box assembly. Due to sudden wind gust, noticeable voltage dips and hence abrupt frequency variation at the side of utility grid make the entire system fasten and therefore proper care must be carried out to eradicate these harms rapidly.

The first and foremost thing to be followed in the erection of wind mill is to choose a proper site of good wind resource which has enormous amount of wind blow throughout the year. A good location for extracting wind energy an area needs to have average wind speed of at least 12 miles/h. After careful inspection of site and large area scanning the proposed wind mill is fashioned in such a way that continuous power input to the utility grid is possible without any interruption. Wind masts are needed to assess the suitability of the site for installing future wind turbines and to give continuous data regarding the wind speed, direction etc.

Though both the major sources of energy namely sun and wind are bountiful, the availability of these resources are subjective and hence it is essential to tap those energies whenever it is feasible and merge those with diesel generator and battery back-up. Wind is air in motion and it derives energy from solar radiation. About 2% of the total solar flux that reaches earth's surface is transformed into wind energy due to uneven heating of atmosphere. Though the harnessing of wind power existed in the past, the effective utilization of wind power reaches its height only in recent years. Wind turbines extract energy from wind stream and converts kinetic energy of the wind to rotational motion required to operate an electric generator.

The actual turbine output depends on the specific design features of turbine blades; the outer profile conforms to aerodynamic performance while the inner profile meets the structural requirements. The degree by which the Wind Energy Generator (WEG) propeller blades are made to tilt through mechanical or electrical controls is called the pitch of the WEG. But technological improvement gains the use of WEGs with better aerodynamic designs, lighter and larger blades made of fiber glass material with epoxy coating, higher tubular towers, direct mesh drive and variable speed gearless operations using advanced power electronics are getting momentum now.

The static characteristics of wind turbine primarily include the turbine design specifications and tower mounting mechanisms. Blades of turbine are made rigid to prevent those from being pushed into the tower by high winds. Moreover, there should be a considerable distance between the tower head and the blade mounting on the hub with a little inclination. During high winds, bending in blades reduces the swept area and hence the wind résistance. In order to improve the performance of the system especially to capture maximum energy and to achieve unity power factor on the line side, variable speed variable pitch wind turbines are typically used. The rotor swept area determines the total energy harvested by a wind turbine from the wind energy. Since the rotor area increases with square of the rotor diameter, a turbine output increases four times. The total power in wind stream is

$$P_m = 0.5\rho A C_p(\lambda,\beta) V^3 w \tag{1}$$

where ρ is the air density, A the area covered with turbine blades, Vw the wind speed, $C_p(\lambda)$ the turbine power coefficient, $\lambda = \omega tur \cdot Rtur/Vw$ the tip speed ratio, ω_{tur} the turbine angular speed, R_{tur} the turbine radius

$C_p(\lambda)$ is the turbine power coefficient which is defined as the ratio of actual delivered power to the free stream power flowing through the uninterrupted area. Tip speed ratio λ is the ratio of turbine speed at the tip of a blade to the free stream wind speed. Optimal tip speed ratio should be maintained throughout the performance of the wind power extraction system to get the maximum power from the wind. The most common design of

wind electric generator preferably incorporates the three bladed turbines. A rotor with an odd number of blades gives more stability compared with the even number of blades. The turbine blades are of two parts namely root area and aerodynamic area which actually converts the wind force into mechanical torque. The aerodynamic area is responsible for power production and the root is joining the aerodynamic portion into hub of wind turbine generator.

Moreover the tower heights should be as twice as the blade length. Most of the wind turbines have gear box assembly which turns the slow rotation of blades into a quicker rotation such as to move the turbine rotor faster. Dissimilar characteristics of the wind turbine persist due to the intermittent nature of the wind and connection with the grid includes the various topologies of wind turbine. The wind electric generator of squirrel cage type with a soft starter and capacitor bank can be directly connected to the utility grid. Asynchronous machine especially wound rotor induction generator with a variable resistance could be suggested to lessen the power fluctuations during wind speed variations. The slip attained is very high in variable speed machines than the fixed speed machines. A doubly fed induction generator is a slip ring induction generator with its rotor windings connected to the grid through AC–DC–AC converter as in Fig. 1. In the other type of configuration the turbine rotor and generator shafts are coupled directly or through gear box.

The next section includes the safe energy source probably the solar energy which uses the photovoltaic technology that identifies the direct conversion of sunlight into electricity by means of solar cells. A solar cell basically a p–n junction diode as in Fig. 2 when illuminated, electron–hole pairs are generated resulting photo current I_{photo}. The generated photocurrent flows in a direction opposite to the forward dark current. Even in the absence of external applied voltage, this photo current continues to flow and is measured as short circuit current I_{sc}. This current depends linearly on the light intensity, as absorption of more light results additional electrons to flow in the internal electric field. The overall cell current I can be given as

$$I_{photo} = I_{out}(\exp eV/kT - 1) - I_{pv} \tag{2}$$

where is the I_{photo} is the total cell current, I_{pv} the light induced current.

Insolation is a measure of solar radiation energy received on a given surface area in a given time. It is commonly expressed as average irradiance in watts per square meter (W/m^2) or kilowatt-hours per square meter per day (kW h/(m^2 day)), or in the case of photovoltaic, commonly measured as kW h/kWp y (kilowatt hours per year per kilowatt peak rating). Irradiance is the radiant power incident per unit area upon the surface sometimes expressed in joules per square meter. In the absence of wind blow or in cloudy climate, the diesel generator can take the position of both and

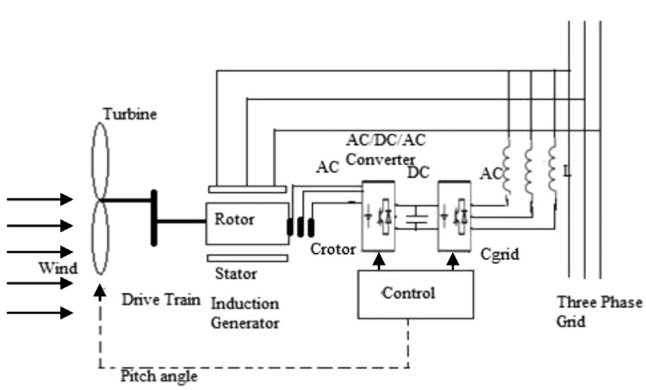

Fig. 1. Doubly Fed Induction Generator in WEG.

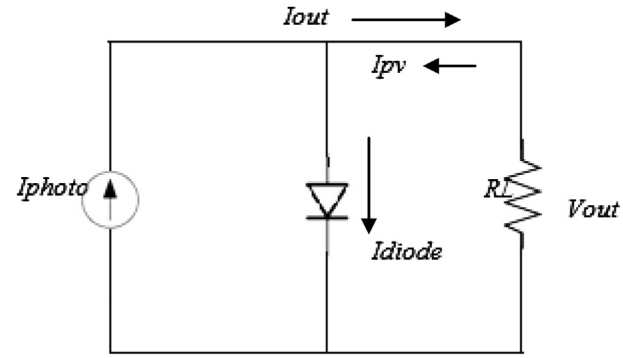

Fig. 2. Model of simple solar cell.

used as a back-up to meet the load demand. Capacitor banks, static VAR compensator and STATCOM are in line so that retrieving optimum energy is still easier.

Although many number of studies on power quality issues and control methodologies [3–22] in hybrid power conversion system have been extensively carried out, there are many challenging tasks remain unsolved.

3. Modeling and simulation of hybrid power systems

The analysis of hybrid power system had been on progress for past couple of years and various control strategies and modeling techniques adopted so far are summarized here. As it is been recognized that most of the wind farms use doubly fed induction generators variable speed machines, the detailed study with its complete modeling is necessary to analyze the same.

3.1. Control strategies

Various methods of control strategies are being analyzed because the amount of energy capture from a WECS depends not only on wind speed at the site, but depends on the control strategy used for the WECS and the conversion efficiency.

Many such methods have been investigated right from the protection schemes to different methodologies used in each individual components of wind electric generation with the help of cited references. To start with, a wind turbine with crowbar protection to guard the power electronic converters during the short circuit behavior is being compared with the conventional machine and the maximum possible value of short circuit current at the rotor terminals has been calculated by means of minimum crowbar impedance additional to that of converter impedance [3].

As all the electrical machines work on the same principle of opposing electromagnetic torque to the mechanical torque, rotational speed of the turbine prime mover varies as a result of change in these torques combined or individually. If the electromagnetic torque is sensitive to the system frequency, then an inertial response will be observed. Though the inertial response has less impact on the system performance, the authors feel that a complete computer model of DFIG should be derived to compare with squirrel cage based wind turbine generator which is of fifth order model. The choice of control strategy incorporated here is of field oriented control (FOC) applied in the field of variable speed drives [4].

Generally the Synchronous generators and fixed speed asynchronous machines liberate kinetic energy from their rotating mass according to the changes of network frequency and DFIG based generators are not prone to this problem; however additional controller with first order filter has been introduced to have

much inertial response so as to modify the rate of change of power injection. A fast dynamic change in rotational speed of the prime mover is traced by an algorithm using the rotor slot harmonics and the rotational speed estimation is been done by Model Reference Adaptive System (MRAS). Sensor less vector control has been discussed here with the method of direct rotor flux oriented (DRFO) for variable speed wind energy generating drives [5].

An extensive control strategy controlling the local bus voltage to prevent the unacceptable voltage peaks in the transmission lines, to get maximum wind power and to reduce the power loss in the proposed induction generator is also been dealt. Conventionally two control schemes are being implemented in the wind turbine model: speed control and pitch control. The speed control can be realized by adjusting the generator power or torque whereas the pitch control is to regulate the aerodynamic power from the turbine.

In order to prevent the damage of induction generator at very high wind speeds, the turbine blades are often designed to operate at lower efficiency during high wind speed (*stall control*), or otherwise the angle of the blades can be actively adjusted according to the wind speed (*pitch angle control*).A little adjust in the pitch angle might cause dramatic change in the power output. The pitch angle variation of wind turbine may lie between -5° and 88° indicating 1511 rpm and1500 rpm respectively. Pitch angle should be less so as to get maximum power output. A special fixed capacitor thyristor controlled reactor type SVC is used here to retain the voltage level by maintaining the power factor at 0.85 leading [6].

Passive or active VAr compensators are also used to control the voltage peaks and to obtain maximum power output from wind turbine and the optimum efficiency of induction machine can be got by changing the air gap flux. A supplementary control loop has been introduced in DFIG controller so as to lessen the speed to a lower value and to enhance the inertial response [7]. The transients in voltage, frequency and finally power can usually be controlled by blade pitch control on turbine side. As the performance is sluggish, a generator side control is improved with the introduction of variable susceptance controller to pick up the transient profile following a torque change. Also the variable susceptance can be obtained by controlling a static VAR system through the firing angle control of thyristors [8]. In low to moderate wind speeds it is not necessary to vary the pitch angle but for high winds is to normalize the aerodynamic power to produce more power output. The wind speed *Vs* pitch angle curve is as shown in Fig. 3. The cut in speed of wind, the wind speed at which a wind turbine start to operate usually is 3.5 m/s.

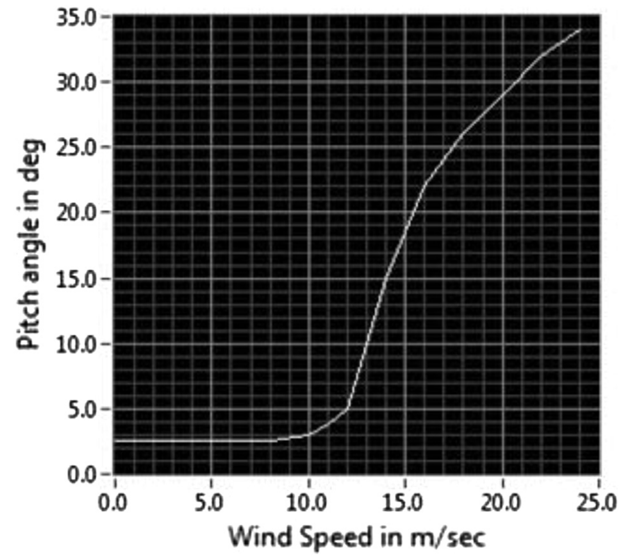

Fig. 3. Wind speed Vs Pitch angle.

The blade pitch control system has been successfully intended to regulate the load bus voltage and stabilize rotor speed for an induction generator in a variable-speed WECS. Also the rotor speed can be adjusted in proportion with wind speed to maintain optimal tip speed ratio. At this tip speed ratio, C_p (λ), turbine power coefficient is at maximum value resulting optimum energy conversion. A software DIgSILENT which has pervasive library of grid components is used along with Matlab, a complete control with soft starter is obtained just in electromagnetic transient (EMT) simulation mode. The change in firing angle results in bulking the size of soft starter and depends additionally on the power factor of the connected element and hence optimum energy conversion [9].

A comprehensive control strategy is developed for a variable speed cage machine in which all three control objectives, i.e. voltage rise, output power and efficiency, are monitored using rectifier and inverter control signals alone and achieved through a double-sided PWM converter [10]. This paper [11] claims that there is a considerable reduction in the harmonics while maintaining the power factor nearly equal to unity by a new method namely vector control of forced commutated inverters. A two reference-frame model is included in the detailed dynamic system to attain decoupled control for STATCOMs real and reactive power control loops. STATCOMs compared to SVCs are faster, smaller and have better performances at reduced voltages and the capability of addressing the transient events is working successfully. Pole placement technique has been developed to determine proper weight matrix for the linear quadratic controller such that eigen values for the closed-loop system can be shifted to desired locations to improve the closed loop performance [12]. This paper presents a DFIG control strategy which develops the standard speed and reactive power control compensating the problems caused by an unbalanced grid by balancing the stator currents and eliminating torque and reactive power pulsations [13].

These authors [14] have developed a novel wind turbine simulator (WTS). The proposed inverter drive scheme is capable of producing a multilevel PWM waveform of phase voltage ranging from a two-level waveform to a six-level waveform depending on the modulation range. This advanced digital control of inverter is useful to integrate the solar diesel system effectively by monitoring the control signals continuously which adjust the angle and magnitude of inverter voltage according to accessibility of sources. Decoupled current control strategy using direct and quadrature current components of the STATCOM is obtained and operation of the complete STATCOM model is discussed here [15]. Switched Reluctance Generator (SRG) can be used to drive a WECS to get maximum aerodynamic efficiency using closed loop control of power output. In the medium and low speed range, the SRG phase current is regulated using PWM control of the magnetizing voltage and for high speeds the generator is controlled using a single pulse mode [16]. In order to interface the SRG to the grid (or ac load) a voltage-source PWM inverter is used.

Power regulation can be accomplished and no babbling effect on generated torque is obtained by Sliding mode control in variable speed WEGs which confer robustness to parametric variations of turbine as well as the generator and grid disturbances. The wind turbine simulator called the fatigue, aerodynamics, structures and turbulence code (FAST) [17,18] is used to validate the simulated result. The main drawback in the modeling of wind turbine is the disparity in the interactions of electrical and mechanical components, some authors have arrived mechanical model with the detailed electrical model and a few concentrated electrical model with a good mechanical representation and hence here FAST,

TurbSim and Simulink packages are collectively used to acquire this proposed model. The recommended strategy here [19] is variable structure controller (VSC) or sliding mode control with different evaluation functions namely sign, integral and sat to boost the power tracking and DC link voltage constant. The error signal of any controlled system is enough to get the controller rules since it contains all the necessary information about the outputs.

The detailed study of making fuzzy rules for designing fuzzy logic controller and modeling the same in Matlab/Simulink Environment has been dealt in [20]. The authors proposed a control scheme for the wind turbine system based on a permanent magnet synchronous generator in this paper [21]. A torque and pitch control schemes has been employed here [22] in which torque controller is designed to maximize the power below the rated wind speed and a pitch controller is designed to regulate the output power above the rated wind speed. Vector control of synchronous machine has been implemented to get torque and flux control and hence optimal extraction of power can be retrieved with optimal reference values of the controller.

3.2. Modeling techniques

The mathematical model of wind turbine, doubly fed induction generator, synchronous generator, power electronic converters are being dealt in many papers [23–48]. Various modeling techniques, tools and the simulation studies are briefly summarized in this section.

Simulink, a window-oriented software based on Matlab is widely used to model the system components for simulating dynamic system and transient behavior of power flow. The complete system has been investigated both in normal condition and perturbed condition for a small step change in the load [23]. The modeling and the performance analysis of wind–diesel hybrid power system for an isolated location has been carried out with a help of PSCAD/EMTDC a software package and the simulations for different wind speed variations has been got here [24]. Though the hybrid power systems are most preferable in recent electrification, it owns problems in implementation and hence requires an adaptable supervisory controller which interacts with the electrical grid and each component analysis is done in this paper [25]. An integrated hybrid Petri nets (HPN) and hybrid automata (HA) is being employed to model the whole system and to design the controller here [26]. A more advanced three layer neural network optimization controller with feedback improves the closed loop performance of the whole system and weights are updated by means of genetic algorithms is discussed in [27]. Diffusion capacitance, double capacitance and charging–discharging resistance has been taken into account to model the lead acid battery which is often used as a energy storage unit in hybrid power systems has been discussed in this paper [28].

Singular perturbation models of typical converters is built here [29] considering the slow dynamics which promotes the consistency between original and reduced system. Parallel operation of DFIG with back to back VSC has lead to low X/R ratio, voltage fluctuations with the coupling effect between the active and reactive power curves, weak grid and islanded operation all requires a control methodology to stabilize the power system is proposed by these authors [30]. As the dynamic control of hybrid power system is very tedious because of its nonlinearity, a novel method namely Particle Swarm Optimization (PSO) based on uniform design and inertia mutation which claims that more efficient control could be attained by using that method. It also tells that more economical and safe operation of the whole system can be brought easily [31]. The hardware realization of energy management and control subsystem is introduced in this paper [32] with the help of multi-agents theory which comprises programmable logic controller, human–machine interface and grid-connected control with a good data acquisition module.

Weibull probability density function is used to get the average wind speed distribution curve based on discrete wind speed frame to obtain the reliability indices, probability of load loss and expected energy not supplied which affect the long term performance of the hybrid power system [33].This paper [34] presents the dynamic modeling and simulation of a hybrid power system comprising solar cell, wind turbine, fuel cell and ultra capacitor to improve the performance of the system considering the load variations and ambient temperature. These authors [35] proposed an experimental system comprising of a wind turbine simulator, a permanent magnet generator, a diode bridge rectifier, a step down converter, a battery bank, a load and a control unit with three phases, and a four wire voltage source inverter under unbalanced voltage conditions. Energy efficiency of hybrid power system is improved by implementing the self-optimizing MPPT algorithm considering the external factors such as temperature, humidity and sunlight intensity and hence to get the nonlinear Volt–Ampere Characteristics curve of solar cells [36]. It adopts double-buck circuit to realize the co-ordination control between wind and solar energy. This paper [37] explores cost effectiveness in renewable energy hybrid system using HOMER to find optimum combination and sizing of individual components by the trial of three demand loads.

Tackling the major issues like efficiency in hardware and control algorithm for controllers is well handled by promoting auto-interference controller and hierarchical fuzzy controller. The auto-interference controller is designed in such a way to capture wind to the highest degree and the fuzzy controller to control the loading and unloading of wind generators, solar cells and grid to augment a fast operation is discussed here [38]. An overall power management strategy is designed for the proposed system to manage power flows among the different energy sources including fuel cell, electrolyzer and the storage unit in the system. A simulation model for the hybrid energy system has been developed using MATLAB/Simulink [39,40]. The co-ordination control method is suggested here [41] for controlling maximum power, load and charging and discharging of battery automatically according to the weather condition and hence obtaining optimization in energy management technique.

A reduced order model has been created for individual components to form a test bench and then an appropriate modeling is being carried out exclusively for unmanned surface vehicles [42]. In the perspective view of small signal, frequency, voltage and transient stability, an autonomous hybrid power system is analyzed even taking the individual models of Automatic Voltage Regulator (AVR), Over excitation Limiter, Load Tap Changer (LTC) and Mechanical Switched Capacitors by means of the recently developed software package called Wind-Hybrid System Simulation Package (WHSSP) in this issue [43].

The modeling and real-time simulation of a generic wind-turbine doubly-fed induction generator in a power system is developed by Matlab/Simulink. The generated code of the Simulink model is linked with Hypersim digital real-time simulator to simulate the power system together with wind turbines [44]. An aggregate wind farm model developed in MATLAB/Simulink environment using ARISTO (Advanced Real-time Interactive Simulator for Training and Operation) simulator system is been discussed in this paper [45]. An intensive analysis of doubly fed induction generator has been tried on power control of both stator and rotor and the simulation results show that the torque-speed characteristics not only depend on stator excitation voltage but can be changed by varying the injected rotor voltage [46]. A novel method has been introduced to model Doubly-Fed Induction Generator for grid-connection studies with switch by switch

representation of PWM converters and a carrier based sinusoidal PWM modulation is done both for converter side and stator flux oriented control. An internal model control is used here [47] to set the controllers precisely. The wind model developed is based on the equivalent transfer function of first or second order in which wind speed is input and the output is active and reactive power here in this paper [48]. The model is suited to simulate the impact of wind speed changes on grid behavior.

4. Fault analysis and management technique in hybrid power systems

Technological advancements are made nowadays for complete elimination or reduction in reactive power consumption by the WEGs. Reactive power is defined as the power required for improving the electromagnetic field generated within the armature coil of the electrical generator of a WEG under static condition to rotate and generate electrical power. The unit size of the WEGs has also gone up from 55–100 kW to 400–750 kW for commercial projects at present. The major issues to be tackled are reactive power compensation, short circuit current at the rotor terminals, total harmonic distortion and flicker emission during faulty conditions [49–53].

4.1. Reactive power compensation techniques

Though induction generators have huge compensation with synchronous generator such as easy maintenance, ruggedness and self protection against overloads and short circuits, the major shortfall lies that it needs reactive power for its operation. In grid-connected system, the induction generators can get reactive power from grid/capacitor banks or else if it is isolated/standalone system it can be supplied by capacitor banks/synchronous generator. Static VAR compensators play a vital role in controlling the reactive power as the mismatch in generation and consumption leads to severe problem like voltage fluctuation at generator side. Three different types of SVCs are used to compare the performance of hybrid power system with IEEE type I excitation and the mathematical model of the complete system is developed with reactive power flow equations [49].

4.2. Short circuit at the rotor terminals

The power electronic converter between the DFIG and the utility grid has to be protected against short circuits that often tend to occur during fault conditions. Further the wind turbine has to be well controlled while operating in variable speed mode; and should continue its operation during system disturbances too. Any change in rotor speed results in a change in the set torque or torque demand. The torque demand is translated into a rotor current demand and compared with the actual voltage rotor current to obtain the rotor-injected voltage. DFIG is also directly coupled to the grid but it has a power electronic converter connected between the rotor windings of the induction machine and the grid. It should have a provision to protect the converter during short circuits [50]. The voltage drop at the terminals would result in large and oscillatory currents in the stator windings of the DFIG. Because of the magnetic coupling between stator and rotor, these currents will also flow in the rotor circuit and through the PEC. The high current impulse can cause thermal breakdown of the converter. Mostly the protection schemes proposed are based on a so called crowbar. During the fault, the rotor windings are short-circuited by a set of resistors. The short-circuit current would flow through this crowbar instead of the converter.

4.3. Total harmonic distortion

The waveform distortion, harmonics and power quality problems affect the entire power system and sometimes cause electric fire and personnel safety hazards. Innovative low cost dynamic control strategy has been adopted to increase the power quality, to reduce the harmonic distortion and to get maximum energy conservation. Reasonable reduction in the Total Harmonic Distortion (THD) is achieved by a Unified Power Filter and Capacitor Compensator (UPFCC) with pulse width modulation technique using switching devices like IGBTs or GTOs [51]. Unlike the fixed capacitor banks, a static VAR compensator can have better control of the voltage profile at steady state and improve the ride-through capability of the wind turbine generators during disturbances. The damage of squirrel cage induction generators which runs at constant speed is prevented by means of pitch control and stall control mechanisms and the turbine blade angle can be actively adjusted according to the wind speed and the turbine blade design is made in such a way that to operate in low efficiency even during sudden wind gust. The overloading effect upon doubly fed induction generators can be reduced by connecting it to the grid by means of a self commutated back to back voltage source converters [52].

4.4. Flicker emission

Flicker emissions of grid connected wind turbines have interdependency on mean wind speed, turbulence intensity, short circuit ratio and grid impedance angle. When the difference between grid impedance angle and the power factor angle comes nearly equal to 90°, the voltage variation and the flicker level is reduced. The fixed speed wind turbine absorbs reactive power from the grid while the variable speed wind turbine with doubly fed induction generators is capable of working with unity power factor and no reactive power is needed. At this position the resistance of the grid line decides the level of flicker emission, as it increases decreasing the grid impedance angle and ultimately reducing the flicker emission [53]. PSCAD/EMTDC is the simulation tool used and controlling the voltage at the Point of Common Coupling (PCC), directly is realized by regulating the reactive power of the PWM voltage source converters. The aim of the voltage controller is to keep the voltage at a constant value such that the voltage fluctuations as well as flicker amount are reduced.

By these thorough studies of dynamic behavior of wind turbine it is seen that the performance of the system is affected by disturbances such as voltage flickering, short circuits in rotor winding and hence thermal break down of power electronic converter and finally the harmonic distortion in the converter all motivate the researchers to set a complete model of DFIG.

5. Converter losses in hybrid power system

The combination of renewable energy sources such as PV arrays or wind turbines, with engine-driven generators and battery storage is widely recognized as a viable alternative to conventional remote area power supplies and normally classified as hybrid energy systems. The design process of hybrid energy systems necessitates the selection of power conditioning devices such as inverters and converters with an efficient energy dispatch strategy. The control strategies of a wind turbine demands the optimal operational performance of the whole system comprising rotor side converter and front end converter which produces pulse width modulated output and losses may occur. The conduction losses in diode and power transistor in power electronic converters commonly happen are summarized here. The diode model

used to evaluate on-state losses in power electronic converters is shown in Fig. 4, where r_D is the ON-state diode resistance and V_D is the threshold forward voltage necessary to put the diode in conduction state. These parameters are characteristics of the diode. Conduction losses in each diode can be calculated as in Eq. (3), where I_D is the average diode current and i_D RMS is the effective diode current.

$$P_{diode} = V_D I_D + r_D i_{Drms}^2 \tag{3}$$

Calculation of losses in static converters used in a hybrid renewable energy system (HRES) is presented in this article [54]. It is intended to evaluate the energy losses in the system during the unit sizing process. In the models developed, conduction and switching losses are considered to note the variation of converters efficiency together with the load variations. Gate-controlled switching semiconductors are used to modulate the static power converters of the proposed hybrid system. Analogous transistor model is used to evaluate conduction losses and can be applied to both IGBT and MOSFET power transistors, where V_{ON} *is* set to 0 when using a MOSFET. Thus, on-state transistor losses in both switching power converters of the HRES can be calculated by

$$P_T = V_{ON} I_T + r_{ON} i_{Trms}^2 \tag{4}$$

Since the losses in power electronic converters affect the overall efficiency of the system, a prediction method has been developed especially designed to analyze the performance of hybrid power system which is interesting for long time dynamic simulations.

This paper [55] includes power loss models with switching losses and conduction losses using bond graph which can be used to predict the system efficiency and for developing realistic balance energy between powers produced by the sources, demanded by load and stored in battery. Significant component losses are the switching losses of voltage source inverters whose operating frequency is proportional to the switching frequency and the switching losses; different inverter control methods have been compared in steady state at various DC link voltages [56]. This paper [57] discusses about integral pulse modulation applied to control both the converters and simulation studies are carried out using Pspice to increase the working efficiency of them. Various converter topologies transient stability of variable-speed wind turbines during pitch control malfunction is to reduce the total harmonic distortion in the quality of energy injected into the grid with is discussed in paper [58].

6. Testing methodologies

Various methods of testing the power electronic converters and many maximum power search algorithms have been adopted increasingly to mitigate the power quality issues and dynamic changes often tend to occur in hybrid power generation systems [59,60]. Proper design of standalone renewable energy power systems is a hard-hitting task, as the coordination among renewable energy resources, generators, energy storages and loads is bit complicated. The types and sizes of wind turbine generators, tilt angles and sizes of photovoltaic panels and capacity of batteries

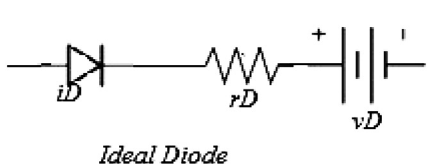

Fig. 4. Diode model for ON state losses calculation.

must all be optimized when sizing a standalone hybrid wind/PV power system. In this paper [59], the genetic algorithm with selective strategy for optimal sizing of standalone hybrid wind/PV power system is being presented. The aim is to minimize the total capital cost, subjected to the constraint of Loss of Power Supply Probability (LPSP). The LPSP of every individual of the GA's population is calculated for 8760 h in a year by simulation.

Output power of wind turbine generators for each discrete wind speed frame is created by splitting the Weibull wind speed distribution curve, is presented in these papers [60,61]. Then a model of battery bank is combined with that of the wind–diesel system. The reliability analysis of the overall system is conducted by combining power outputs of the wind and diesel generation units with battery throughout all wind speed frames to obtain the reliability indices, Loss of Load Probability (LOLP) and Expected Energy Not Supplied (EENS), which reflects a long term performance of the hybrid power system. By making use of wind speed frame, the intermittent characteristics of wind speed and turbine failure can be easily identified. Here [62] the proposed method uses a standard evolutionary programming (EP) as a base level search, which enhance a quick search towards the optimal region, and local optimization by Sequential Quadratic Programming is again employed to do fine hunting.

A new MPPT algorithm is drawn to track the wind speed and to synchronize the inverter with rotating speed of the generator thus avoiding the dead time effect. A low pass filter is used at the output of the MPPT controller to decrease the fluctuations of the rotating speed reference. The resulting system has very good efficiency, lower cost and fast, stable tracking speed [63]. This paper [64] presents a comparative simulation study between two different approaches applied to harmonic mitigation on PMSG WECS. The recent techniques include harmonic trap filters (HTF) and single-switch three-phase boost rectifier (PFC).

This work [65] describes the development of a new algorithm namely Particle Swarm Optimization for the solution of a multi-objective problem in power systems with wind. Basically, the purpose is to search an optimal operation point of system which allows power factor remote control and loss minimization simultaneously. In this referred journal [66], the reactive power optimization is handled with the fuzzy based PSO method and is far more superior to other evolutionary methods and can be used as a new tool for reactive power planning. A methodology for calculating the optimum size of a battery bank and the PV array for a standalone hybrid wind PV system is developed is dealt in [67]. Long term data of wind speed and irradiance recorded for every hour of the day for 30 years had been used for a given load and a desired Loss of Power Supply Probability, allowable number of batteries and PV modules has been calculated with minimal cost. The performance and stability of the proposed wind/diesel hybrid power system with variable loads has been evaluated considering the disturbances like change in wind speed with the help of PSCAD/EMTDC [68].

A complete mathematical modeling of individual components of hybrid system with the reliability model based on the loss of power supply probability (LPSP) and the levelised cost of energy (LCE) is quoted here [69]. Single current sensor is used to extract power from several solar panel assemblies and hence ultimate reduction in board size is achieved by increasing the number of microcontrollers or FPGAs that suits the application. Perturbance and Observance algorithm is used here to perturb the duty ratio of converters and been perturbed turn by turn and the steady state load current is sensed and stored [70]. A maximum power point tracker for a photovoltaic panel guarantees greater than 99% tracking accuracy and fast convergence by RCC Ripple Correlation Control, an online optimization technique is been dealt in this reference [71]. When the PV arrays get shadowed either partially

or completely, the solar extraction becomes difficult due to random number of multiple peaks and *I–V* and *P–V* characteristics is not uniform and an innovative approach is tried here [72] to get optimum insolation and irradiance from sun. The PV cells in module are grouped in such a manner to have only one peak at a time considering the effect of bypass and blocking diodes in the circuit after carefully studying the configuration of PV array and shading pattern. Addition of fuel cell with a PV array minimizes voltage dip in the output and hence eliminates the usual DC–DC boost converter. An uninterrupted integrated hybrid power supply is offered to the grid and a small amount of PV power can be fed into the grid. β Method in fast MPPT scheme with suitable modification is implemented here [73] with maximum insolation and high temperature. A control system is realized with a fuel cell generation device in a photovoltaic–wind existing plant and function of the plant is carried out with the combination of diesel generator and battery [74].

Artificial Neural Network is been adopted for modeling a photovoltaic module and Levenberg–Marquard back propagation optimization function is used for training the network. The efficiency of the constructed neural model has been evaluated by comparing the predicted value with the real time data [75]. Without a wind speed sensor, maximum wind power can be obtained by measuring the wind blow for every second in fixed pitch wind turbine with an induction machine. The system measures the power generated by the turbine and keeps on changing generator speed so as to increase the total power and a noticeable improvement is seen with variable speed wind profiles [76]. This paper [77] describes a solar photovoltaic fuel cell (PVFC) hybrid generation system consisting of a photovoltaic generator, a proton exchange membrane fuel cell (PEMFC), an electrolyzer, a super capacitor, a storage gas tank and power conditioning unit (PCU). Excess PV energy can be converted to hydrogen using an electrolyzer for later use in the fuel cell and the load is met by the PV generator with a fuel cell working parallel.

Here [78] the operational aspects of network grid such as power quality, voltage instability near grid, transient interaction between wind turbine generator and grid can be minimized by a soft starter and a thyristor based soft start module. These papers [79,80] try to accomplish efficiency optimization and performance enhancement control by analyzing the performance of a variable speed wind generation system using fuzzy logic principle. The configuration has full control over electrical torque, speed and reactive power compensation. A comparative study of 10 widely-adopted MPPT algorithms and their performance have been evaluated on energy point of view at different solar irradiance variations using Simulink is discussed in [81]. A ripple correlation control is achieved in [82] with low cost MPPT and Pspice simulation is carried out and observed that when solar illumination varies, the controller rapidly shifts the system operating point to an updated MPP. A new method is here [83] to improve the tracking speed of the MP&O namely the EPP which uses one estimate mode between every two perturb modes. The present strategy employs a single voltage sensor and carries out simple computation for a buck converter-based MPPT. The EPP method significantly improves the tracking accuracy and speed of the MPPT control compared to other methods.

A multi-agent theory technique has been adopted and a Multi-agent model of the WSHGMAS (wind and solar energy hybrid power generation multi-agent system) including data collecting and processing, control, info-management, resource-management, wind and solar energy power generation agent modules which makes the system output stable, with better performance is established [84]. As the cost of energy and investment of hybrid power system is increasingly high an appropriate combination of system reliability indices with capital cost is introduced by means of hybrid particle swarm optimization (PSO)/harmony search (HS) approach, and found that the system attains the optimal solution without affecting the reliability [85]. The modeling of generator and individual components has been arrived systematically in Simulink window and corresponding outputs are depicted here [86]. In this paper [87], modeling of wind conversion system as a whole is carried out and vector control strategy is adopted with various outputs obtained with and without controllers at constant and variable wind speeds.

7. Conclusion

By carefully analyzing and reviewing the reference papers cited here, the overall idea about hybrid power system is well understood and maximum power extraction can be achieved in hybrid power system with advanced technologies such as genetic algorithm, neural network and fuzzy logic control strategies. In recent times the supervisory control system with good data acquisition plays a vital role in getting the desired power output in wind electric energy systems. The most accurate modeling can be obtained considering both the mechanical and electrical characteristics of the individual components simultaneously. Also the optimum power search can be acquired with new MPPT technologies in PV arrays and wind power generation.

Finale with the hope that the hybrid power system challenges near future with its own potential which absolutely pave a new era with effective and efficient energy moderation. Special mention to renewables has been made throughout the world to have green future and sure renewables are going to great heights to protect earth down from horizon. Renewable energy may supply more electricity than nuclear reactors or natural gas by 2016, urged by declining costs and growing demand in emerging markets, the International Energy Agency said. The U.S. Department of Energy will update its 20% Wind Energy by 2030 report, which indicates an increased level of wind penetration is not only possible but feasible. This statement comes true for every nation.

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